Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 70 (2015) 523 – 527
Physics Procedia

2015 International Congress on Ultrasonics, 2015 ICU Metz

Application of a Full Hybrid Ultrasonic System to Improve the Steelmaking Practices

Dimitri Kurzepa[a], Gilles Gremeaux[a], Benoit Krebs[a,]*

[a]*ABS Centre Métallurgique (ACM), 10 rue Pierre Simon de Laplace, Metz 57070, France*

Abstract

This paper exposes the performances of a full hybrid ultrasonic system in terms of accuracy, sensibility, pooled volume, size of defect and time of analysis. The contributions of the high-frequency control with regard to the low frequency ultrasonic control and the conventional characterization techniques of steels are also explained. The fine analyses obtained allow advanced study of either the manufacturing processes and their optimization. This technique adapted to the challenging markets allows handling the most demanding customers of high quality steel grade. Perspectives in terms of product improvement and experimental techniques development are also discussed.

Peer-review under responsibility of the Scientific Committee of ICU 2015

Keywords: full hybrid system; ultrasonic control; low and high frequencies; manufacturing processes improvement; steel characterization

1. Introduction

Since several decades, experimental studies are led by steelmakers to improve their steel's manufacturing processes and to better understand the various phenomena which influence the in-use properties. It is well established that the presence of non-metallic inclusions in steel is detrimental in particular for the fatigue lifetime (Cogne et al., 1986, Kobayashi et al., 1986, Baum et al., 1987, Lormand et al., 2002, Hashimoto et al., 2011, Bhadeshia, 2012). More the final application is demanding (i.e. higher is the in-service load) lower the critical size of the inclusions is (see in Fig. 1, Daguier et al. 2002, Fougères et al. 2002). Long and expensive fatigue tests are implemented by the most demanding end users to select and follow the quality of their suppliers.

* Corresponding author. Tel.: +33 3 55 94 40 09; fax: +33 3 55 94 40 38.
E-mail address: b.krebs@absacciai.it

Peer-review under responsibility of the Scientific Committee of ICU 2015
doi:10.1016/j.phpro.2015.08.007

To shorten and reduce cost of characterizations, end users and steelmakers develop various techniques to measure the distribution of inclusions in steels (Auclair et al. 2002, Ruby-Meyer et al. 2007). In particular, ultrasonic inspection is a very powerful tool to detect inclusions responsible of components failure.

This article gives examples of application of the immersion ultrasonic tank prototype used at ACM.

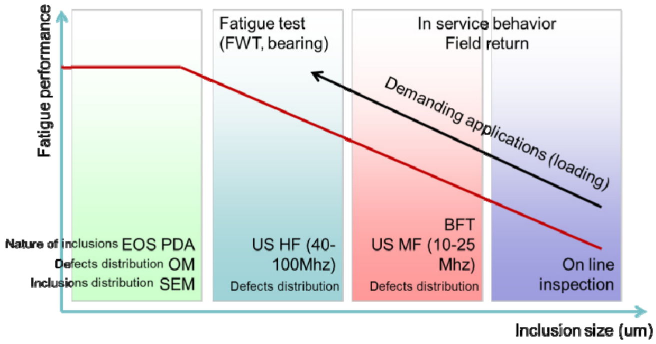

Fig. 1. Fatigue performance, inclusion size and adapted characterization methods

2. Hybrid ultrasonic immersion testing device

To optimize the product characterization, ACM invested in an Hybrid ultrasonic immersion testing device. This device is able to scan specimens at low frequency (10Mhz) for the macro cleanliness control and high frequency (50Mhz) for the meso-cleanliness evaluation (Fig. 2a).

Concerning the tank, a coding system is used for the movements with an accuracy of 0,01mm for the four motorized axes: the Cartesian axes X, Y and Z for the up/down and the translation movement and an axis A for rotation of cylindrical samples. The coupling medium is water; a system of filtration allows to maintain the cleanliness of this one.

Two working modes are available:

- The control by low-frequency ultrasounds. The frequency is 10Mhz. This mode of control allows to control the macro cleanliness of steels: we speak in this case about defects higher or equal to 300 microns FBH.
- The second mode of possible work is the control high-frequency ultrasounds. The frequency is actually 50Mhz. This allows to control the meso cleanliness of steels: we speak then about defects which can go down to 50 microns.

For the low frequency analyses, the system is equipped with a eight channels transmitter/receiver card and a 10MHz probe supplied by Metalscan. Bars from diameter 30 to 160mm and plates can be controlled. The control time is about twenty minutes for a cylindrical bar of 500mm length.

For the high frequency, one channel transmitter/receiver card and 50 MHz probe supplied by Olympus are used. Higher frequencies are useful to find smaller inclusions. Plate of 60 by 60mm and 10mm thick can be controlled for a control time of about nine hours per plate.

The same exploitation software MIDAS works for both 10MHz and 50MHz frequencies analyses.

Ranges of indication size and control time are superimposed in Fig. 2b for in-line control at ABS plant and ACM devices.

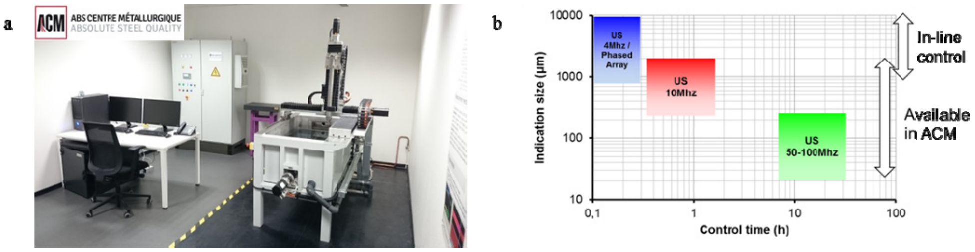

Fig. 2. (a) hybrid ultrasonic immersion testing device; (b) ranges of indication size and control time

3. Improvement of the macro-cleanliness by 10MHz analyses

3.1. Steelmaking process

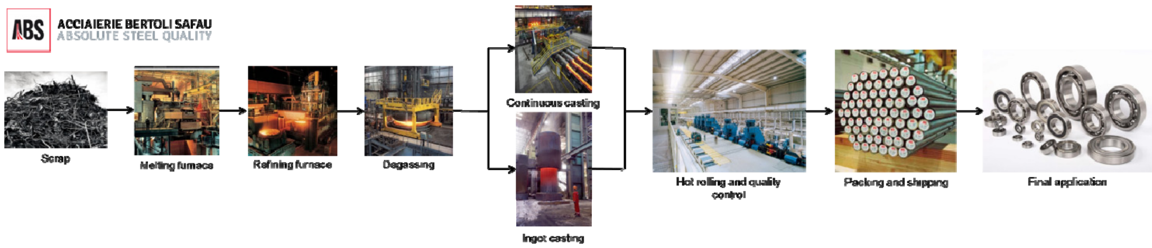

Fig. 3. Outline of the steelmaking process.

ABS plant is equipped with two melting lines, and for each line a 100-ton capacity electrical furnace. The melting process (schematized in Fig. 3) is fed by loads of scrap selected according to the different kinds of steel. The additions and ferroalloys are performed by automated devices connected to the process supervision and monitoring system, which keeps under control permanently all the production parameters (technical, metallurgical and consumption). The production is completed with the refining process and with vacuum degassing, in order to guarantee particularly low hydrogen content and high quality steel grades. At the end of the melting phase, after checking all the metallurgical parameters, melted steel is directed to the casting lines. The flexibility of the ABS production line is achieved through two casting lines:

- Bottom-poured ingots casting;
- Continuous casting as round sections.

The rolling mill is composed of 17 subsequent rolling units (in horizontal and vertical configuration) and a Kocks block with three roll concept, used as a finishing stand. This mill is fed with continuous casting products. Depending of the customer specifications, bars can be cold finished for close tolerances and excellent surface quality. Bars are sent to the customer to manufacture final products.

3.2. Macro-cleanliness inspection to optimize the steelmaking practices

As explained before, after vacuum degasing, the molten steel inside the ladle is routed to the continuous casting machine (see the illustration in Fig. 4). The liquid steel is transferred to the tundish and distributed inside the mold of the different strands. The solidification begins inside the mold and continue along the strand. When the product is totally solidified, blooms are cut to the right length.

For the need of the studies, several heats have been mapped, on every blooms, to follow the evolution of the cleanliness during the casting (the characterizations were performed on the rolled products).

10MHz measurements show a continuous decreasing/improvement of the cleanliness index all along the casting but, by applying the process 1, the beginning of the heat is perturbed by the transitory regime in the tundish.

By implementing several improvements (process 2), results obtained are much more better in terms of macro-cleanliness.

The reduction of the density and the size of the inclusions make more and more difficult their detection, some requests concern smaller defects, so higher frequency is needed to detect them.

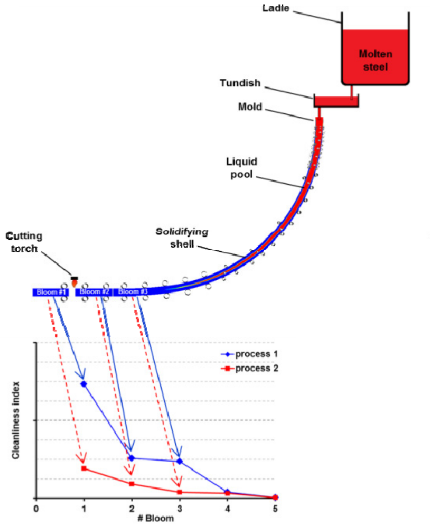

Fig. 4. Evolution of the macro-cleanliness index during the casting for two different processes (characterizations on the rolled products).

4. Application of the 50MHz inspection for fatigue failure of bearings

For very demanding applications (like high loaded bearings), 10MHz inspections are not enough to guarantee the fatigue performance of the bearing steel. Indeed, critical size of inclusions decreases when the Hertzian pressure increases. The fatigue failure of bearings due to non-metallic inclusions is a 3 step process :

- Crack initiation inside the material generally in regions where there are inhomogeneity's: inclusions, porosities, for example.
- Fatigue crack propagation.
- Spalling.

Bearings manufacturers perform long fatigue tests to select steel for bearings. These tests can take several months for this specific application. Theoretical studies showed that the inclusion critical size for fatigue damage are greater than 20-30 µm. Then we can expect a correlation between the size and the density of inclusions detected by us 50Mhz and the fatigue performance of the steel.

For the sample analyzed in Fig. 5, no indication were found after the 10MHz inspection but five indications with a FBH equivalent higher than 50µm were found after 50MHz analysis (4 at the center of the bar and only one outside), sign of a potential fatigue failure for very high loaded bearing.

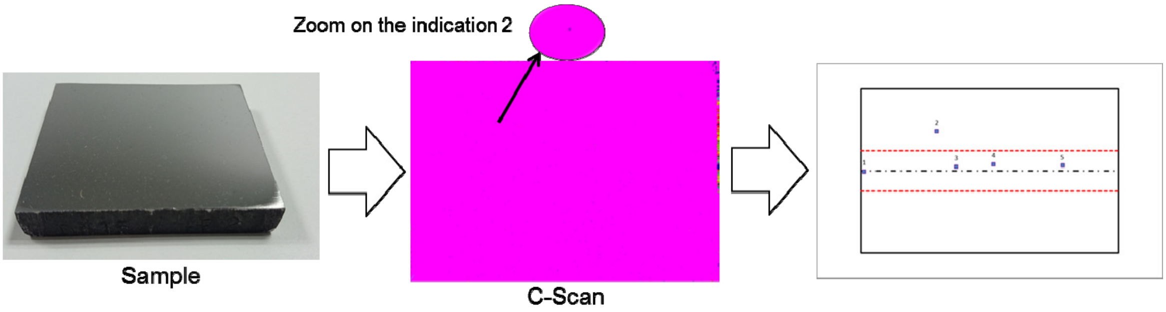

Fig. 5. Example of inclusions distribution determinate by High-frequency ultrasonic testing

5. Conclusion

This paper details the possible applications of the full hybrid ultrasonic system available in ACM. With the same device, analyses can be performed either with 10MHz or 50MHz frequencies. Standard low frequency analyses are positively supplemented by high frequency analyses: the whole range of inclusion size can be explored. Correlations are expected between high frequency control and fatigue tests. The outcome of these developments, thanks to bearings manufacturers collaborations, will maybe replace certain tests, allowing important saving of time and cost for the most demanding customers.

References

Auclair, G., and Daguier, P., 2002. Appropriate Techniques for Internal Cleanliness Assessment, In: Bearing ,Steel Technology ASTM STP 1419, Beswick, J. M. (Ed.), American Society for Testing Materials International, West Conshohocken, pp. 108.

Baum, R., Böhnke, K., Boeckers, T., Klemp, H., 1987. Effect of steel manufacturing process on the quality of bearing steels, In: Hoo J. J. C. (Ed.), American Society for Testing Materials International, Philadelphia, pp. 360.

Bhadeshia, H. K. D. H., 2012. Steels for Bearings. Progress in Materials Science 57, 268-435.

Cogne, J. Y., Héritier, B., Monnet, J., 1986. Cleanliness and fatigue life of bearing steels. In: Clean Steel 3, The Institute of Metals, London, pp. 26-31.

Daguier, P., Baudry, G., Bellus, J., Auclair, G., Rofès-Vernis, J., Dudragne, G., Girodin, D., and Jacob, G., 2002. Improved Bearing Steel for Applications Involving Debris, Higher Loads and Temperatures. In: Bearing Steel Technology, ASTM STP 1419, Beswick J. M. (Ed.), American Society for Testing Materials International, West Conshohocken, pp. 324.

Fougères, R., Lormand, G., Vincent, A., Nelias, D., Dudragne, G., Girodin, D., Baudry G., and Daguier, P., 2002. A New Physically Based Model for Predicting the Fatigue Life Distribution of Rolling Bearings. In: Bearing Steel Technology, ASTM STP 1419, Beswick J. M. (Ed.), American Society for Testing Materials International, West Conshohocken, pp. 203.

Hashimoto, K., Fujimatsu, T., Tsunekage, N., Hiraoka, K., Kida, K., Santos, E. C., 2011. Study of rolling contact fatigue of bearing steels in relation to various oxide inclusions. Materials and Design 32, 1605–1611.

Kobayashi, K., Tsubota, K., Sakajo, T., Muraoka, T., Sugiyama, H., 1986. Fracture characteristics of bearing quality steels. Trans. Iron Steel Institute of Japan, 26.9.

Lormand, G., Piot, D.,Vincent, A., Baudry, G., Daguier, P., Girodin, D., and Dudragne, G., 2002. Application of a New Physically Based Model to Determine the Influence of Inclusion Population and Loading Conditions on the Distribution of Bearing Lives, In: Bearing Steel Technology, ASTM STP 1419, Beswick J. M. (Ed.), American Society for Testing and Materials International, West Conshohocken, pp. 493.

Ruby-Meyer, F., Hénault, E., Rocher-Bakour, M., Merchi, F., 2007. Improvement of inclusion cleanness in bearing steel and Catreated steel. Metallurgical Research and Technology 104 12, 585-590.